DOCUMENT RESUME

ED 406 171 SE 059 835

AUTHOR Niedderer, Hans
TITLE Learning Process Studies in Physics: A Review of Concepts and Results.
PUB DATE Mar 97
NOTE 20p.; Paper presented at the Annual Meeting of the American Educational Research Association (Chicago, IL, March, 1997).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Cognitive Development; Educational Strategies; Educational Theories; Elementary Secondary Education; Foreign Countries; Misconceptions; *Physics
IDENTIFIERS Alternative Conceptions; *Conceptual Change

ABSTRACT

Investigations of changes of conceptions during physics instruction are the logical and necessary next step to follow the successful international research on students' pre-instructional conceptions. This paper reviews theoretical issues, selected content-specific results, and general hypotheses. It is oriented towards explicit cognitive descriptions related to contents of physics, coming to cognitive states and cognitive processes. Some evidence is given for "intermediate conceptions", mainly as a result of self-development of the cognitive systems of students. Further aspects described include a different view on the final state of the cognitive system after teaching, and a differentiation of "conceptual change" towards learning as formation of additional cognitive structures versus learning as the change of qualities of structures already there. Contains 42 references. (Author/NB)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED 406 171

Learning process studies in physics:

A review of concepts and results

Hans Niedderer

Institute for Physics Education, University of Bremen,
D 28334 Bremen, Germany

Abstract

Investigations about changes of conceptions during physics instruction are the logical and necessary next step to follow the successful international research on students' pre-instructional conceptions. The present paper reviews theoretical issues, selected content specific results and general hypotheses. This is oriented towards explicit cognitive descriptions related to contents of physics, coming to cognitive states and cognitive processes. Some evidence is given for "intermediate conceptions", mainly as a result of self development of the cognitive system of students. Further aspects are a different view on the final state of the cognitive system after teaching and a differentiation of "conceptual change" towards learning as formation of new additional cognitive structures vs learning as change of qualities of structures being already there.

PERMISSION TO REPRODUCE AND
DISSEMINATE THIS MATERIAL
HAS BEEN GRANTED BY
H. Niedderer

TO THE EDUCATIONAL RESOURCES
INFORMATION CENTER (ERIC)

Paper presented at 1997 AERA

Annual Meeting in Chicago

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION
CENTER (ERIC)
This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.
• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

Hans NIEDDERER
Physics Departement,
Institute for Physics Education
University of Bremen
Postbox 330440
28334 Bremen, Germany

Phone: 49-421-218-2484 / 4695
Fax: 49-421-218-4015
e-mail: niedderer@physik.uni-bremen.de

S0059035

BEST COPY AVAILABLE

Learning process studies in physics: A review of concepts and results

Hans Niedderer

University of Bremen
Institute for Physics Education

1. Why content related research on learning processes?

The following paper will analyze empirical learning studies in physics instruction. My special interest are empirical studies continuously recording learning processes in real class room instruction and aiming at analyzing the results in view of the change of cognitive structures. In addition, I consulted studies describing in some detail the final cognitive state after a learning process.

An increasing number of researchers in physics education turning to a constructivist paradigm, such learning process studies appear to be an objective of some significance. If you follow von Aufschnaiter (1991) that learning is a self development of a cognitive system, learning process analyses having a cognitive approach are obligatory. In addition to the content orientation of the learning offers (teacher, media, written texts etc.) the analysis of the effects of learning environments (particularly of students' activities) on the students' actual learning process should be focused. An appropriate modeling in view of content related purposes of students' cognitive systems appears inevitable in this context in order to make possible a clear distinction of the students' learning processes as compared to the process intended by the teacher. Thus, evidence of students' learning processes not intended by the teacher is of specific interest (e.g. Niedderer & Goldberg, 1995).

A further aspect is favoring a content related research field "learning process analysis". The most successful field of research in the past twenty years in physics education has been the investigation of students' conceptions shown on world wide conferences and bibliographies (Pfundt & Duit, 1994; Carmichael et al., 1990). From the cognitive point of view the research results are descriptions of cognitive states, mostly before teaching, sometimes after teaching. To be able to judge, however, learning effects of curricula, media, certain types of instruction, and teacher approach the change of such cogntitive states in the course of instruction and the processes involved have to be investigated. Probably also for teachers appropriate cognitive models are of importance for a better understanding of their own action. Von Glasersfeld (1992) says in this respect: "... in order to teach one must construct models of those "others" who happen to be the students." A further step in research development relating to "students' conceptions", aiming at the description of temporal processes of change of such students' conceptions appears to be the need of the hour. This was also the purpose of an international workshop held in Bremen in 1991 (see Duit, Goldberg & Niedderer, 1992).

At the moment, in Bremen three research teams (v. Aufschnaiter, Niedderer and Schwedes) are working on the subject of learning process studies in physics instruction. Common to all of them is the concentration on studies during instruction, using qualitative case studies with individual students of different age groups in real instruction contexts. The teams are working, however, on a partly different theoretical basis. In the team von Aufschnaiter learning is mainly analyzed and described as development of complexity under rather structural aspects. In the team Niedderer, content related modification of cognitive elements such as alternative frameworks, conceptions, schema etc. are used to describe learning. In the team Schwedes further development of the "conceptual change" approach together with analogies form the most important theoretical basis.

2. Comments on a theoretical frame used in content related investigations

2.1 Description of the cognitive system in physics learning

Description of content related parts of the cognitive system in physics learning has been carried out in the two following ways:

- *Propositional knowledge*. In this method terms (conceptions) are chosen and subsequently statements are formulated which can be supposed to be student's "mini theories" and thus can serve to explain his behavior in speaking and acting. This area comprises (students') ideas and mental models.

- *Description of concept maps or conceptual maps.* This method shows in graphs the most significant terms and their interrelations which are supposed to have a behavior generating structure for the student.

The display of cognitive structures in the form of "ideas", "pre-concepts", "conceptual structure" or "conceptions" and their relations seems to be important, perhaps even indispensable for didactic issues. This raises, however, the following problem: does the assumption of representation of such content related cognitive structures possibly prevent to realise more general production systems within the cognitive system which might explain the constructions and learning processes observed in a simpler and more general way? In our[1] opinion such production systems or tools might still have a considerable explanatory potential, up to now only partly disclosed for the area of schema. For studies in physics education, however, the following attitude seems to me specifically fruitful until a satisfactory evidence of such more general production systems is given: We handle content descriptions of cognitive systems (e.g. as "conceptions") as if they were stored in mind (representation of knowledge), knowing that this is only a comfortable type of presentation which will have to be replaced later by description of more general production systems or "generating structures" of the cognitive system with declarative and procedural

---

[1] "our" in this context means my construction of consenses from the discussion in the Institute of Physics Education at the University of Bremen.

parts.[2] Thus, conceptions are content related characterisations of especially frequent or probable actual constructions of students.

2.2 Basic terms "learning" and "learning process"

From the papers mainly of the Bremen working groups in the past few years it appears necessary to describe learning processes on different levels: as students' current construction processes during instruction which in the long run may, but not necessarily, lead to learning; as "learning pathways" with virtually stable intermediate states in the learning process, as modification of characteristics of such cognitive structures, and finally as effective cognitive construction processes causing transition from one cognitive state to the next. These meanings are compared in the following diagram:

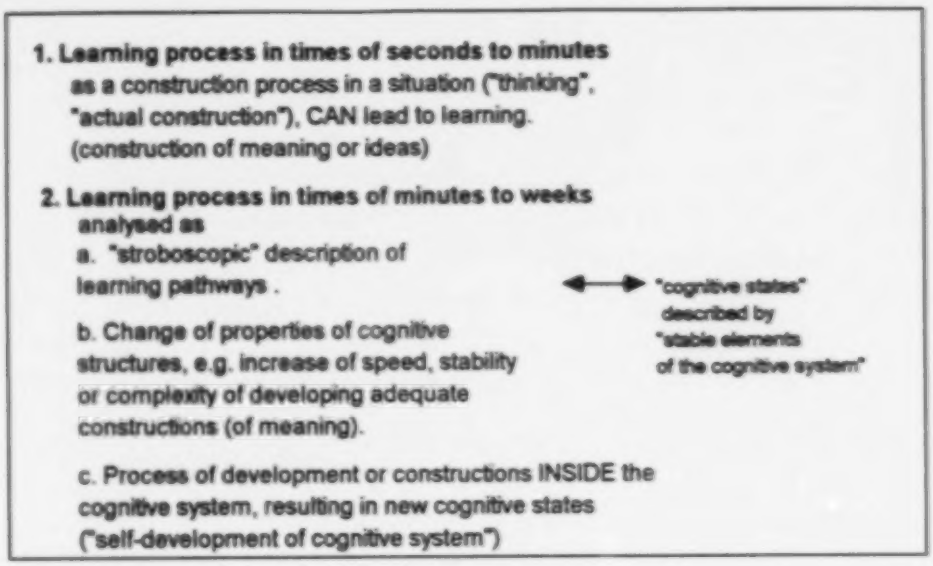

1. Learning process in times of seconds to minutes
as a construction process in a situation ("thinking", "actual construction"), CAN lead to learning.
(construction of meaning or ideas)
2. Learning process in times of minutes to weeks
analysed as
a. "stroboscopic" description of learning pathways .
"cognitive states" described by "stable elements of the cognitive system"
b. Change of properties of cognitive structures, e.g. increase of speed, stability or complexity of developing adequate constructions (of meaning).
c. Process of development or constructions INSIDE the cognitive system, resulting in new cognitive states ("self-development of cognitive system")

Fig. 1: Different meanings of learning

The distinction of current constructions and stable cognitive elements is also emphasised in the model of a content relevant description of the cognitive system proposed by Niedderer and Schecker (see Fig. 2).

As is shown from the results of various empirical studies in physics instruction, learning is described on the one hand as development of new cognitive structures and, on the other hand, as modification of certain characteristics of these structures (see Fig. 3). In the first case, we have a long tradition of empirical and theoretical research using the term "conceptual change". In the course of this research the originally existing idea of replacing false ideas (misconceptions) by correct conceptions has been replaced by the notion, that the learning process is a

---

[2] The "cognitive tools for knowledge construction" noted in Niedderer & Goldberg (1995) include as essential elements also schema and other linguistic basic elements and seem to be very close to such "production systems".

development of parrallel cognitive structures (conceptual addition, conceptual growth, conceptual development) (Duit 1997). There exist already numerous research results on the second way of learning as shown in this paper.

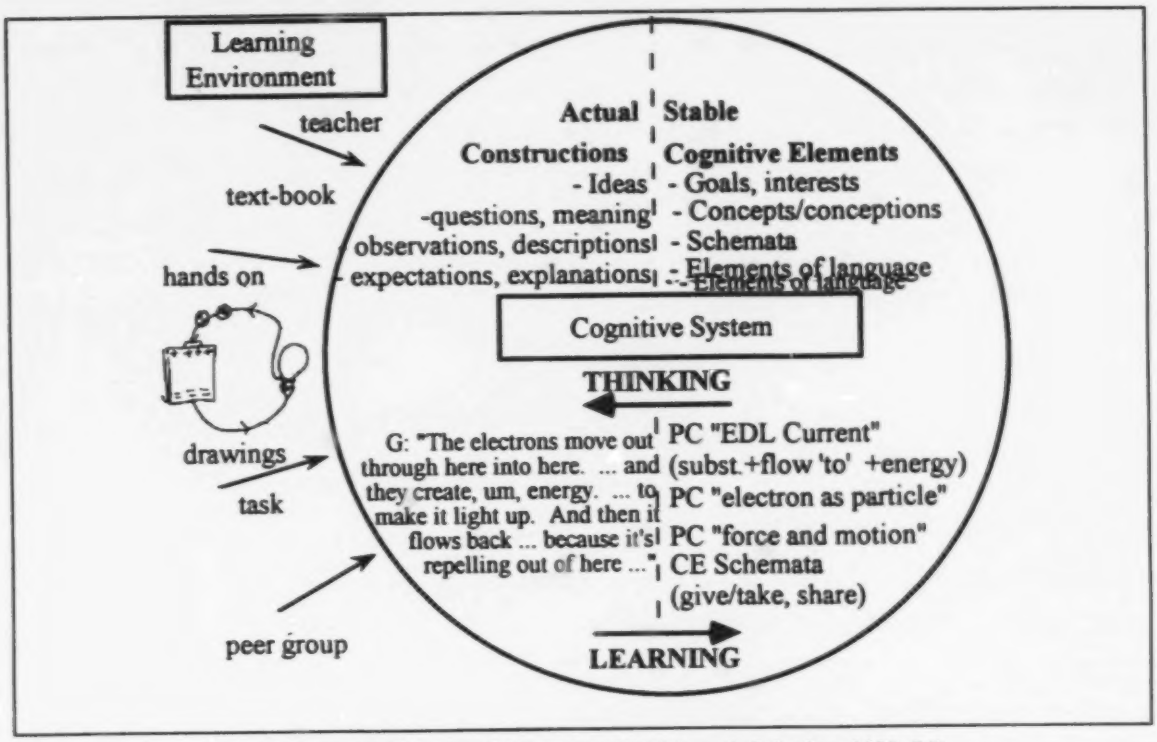


Fig. 2: A model of the cognitive system (Niedderer & Schecker, 1992, 84)

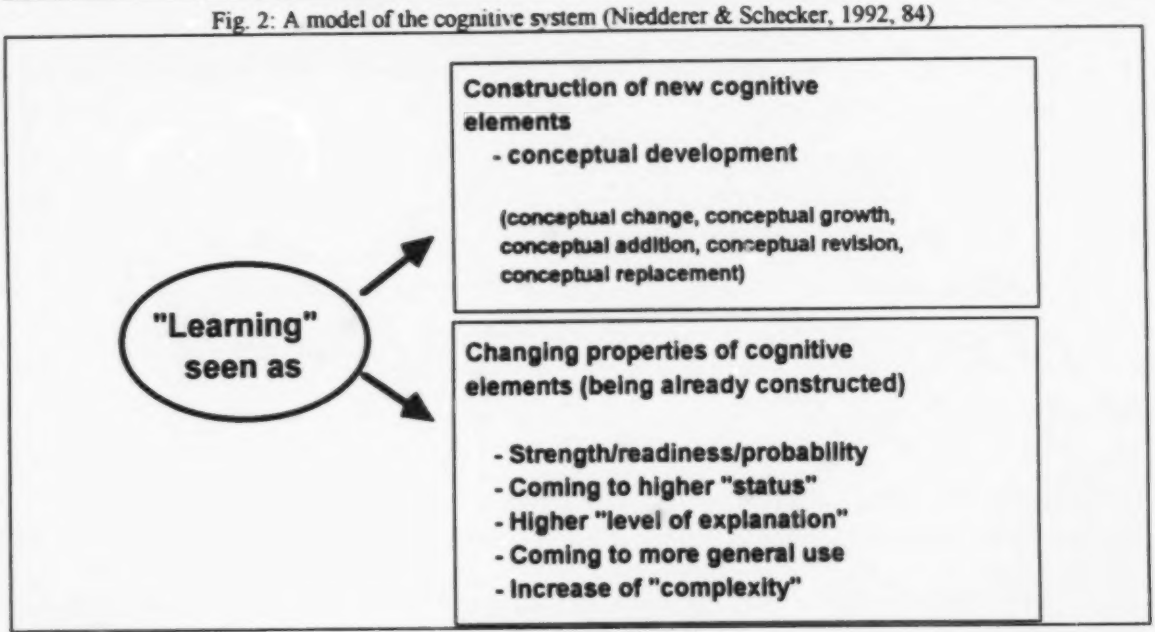

"Learning" seen as
Construction of new cognitive elements
- conceptual development
(conceptual change, conceptual growth, conceptual addition, conceptual revision, conceptual replacement)
Changing properties of cognitive elements (being already constructed)
- Strength/readiness/probability
- Coming to higher "status"
- Higher "level of explanation"
- Coming to more general use
- Increase of "complexity"

Fig. 3: Two ways of learning

2.3 Content related description of learning processes - an example

In the following example a learning pathway is described as a sequence of cognitive states, each state characterised by a conceptual map (fig. 4):

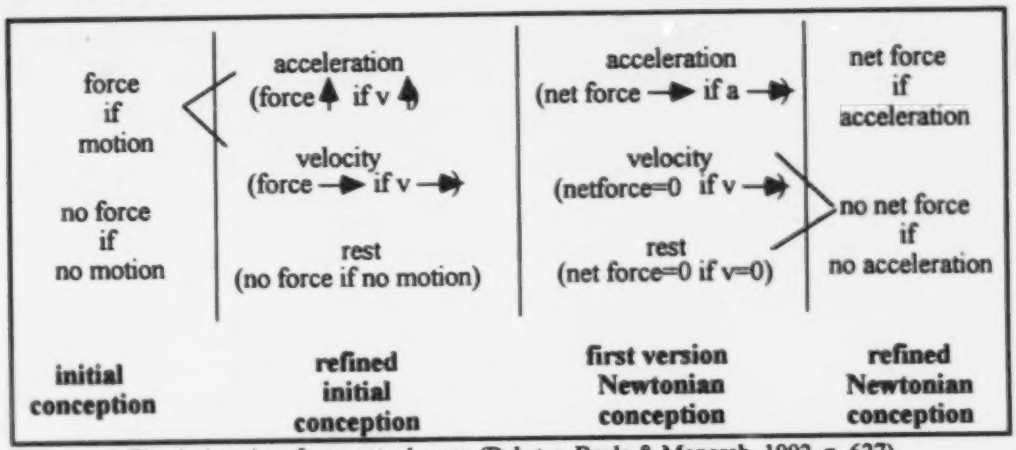

force if motion
no force if no motion
acceleration (force ↑ if v ↑)
velocity (force → if v →)
rest (no force if no motion)
acceleration (net force → if a →)
velocity (netforce=0 if v →)
rest (net force=0 if v=0)
net force if acceleration
no net force if no acceleration
initial conception
refined initial conception
first version Newtonian conception
refined Newtonian conception

Fig. 4: A series of conceptual maps (Dykstra, Boyle & Monarch, 1992, p. 627)

The figure shows a description of four cognitive states as "initial conception", "refinded initial conception", "initial Newtonian conception", and "refined Newtonian conception". These four states are described by key conceptions and their interrelations (arrows) partly showing modified meanings. If, for example, the first state includes an arrow "force causes motion" and the third as well as the fourth state an arrow "net force causes acceleration" this modification also means a change of the concept force: in the first case force is essentially characterised as cause of all motion while in the second case the resulting force is only relevant for generation of acceleration.

3 Empirical design of the studies

Continuous data collection during instruction

As already noted my main interest is for such empirical studies using continuous data collection during instruction as main data basis. On the whole sixteen empirical studies of this type have become known to me in the field of physics instruction (Scott, 1987; Brown, 1987; Brace, 1988; Fischer, 1989; Schmidt, 1989; Lichtfeldt, 1992; Roschelle, 1991; Lewis, 1991; Katu, 1992; Tytler, 1994; Welzel, 1994; Seibel, 1995; Komorek & Duit, 1995; Wodzinski, 1995; Niedderer & Goldberg, 1995; Petri, 1996). Most of these studies are published as doctoral dissertations. Six of them come from the three Bremen research groups. The main data basis are audio and video records of normal classroom instruction subsequently transcribed. In their following interpretive analysis the Bremen studies differ from all others in their much more detailed manner to record, analyze, and model the cognitive processes of individual students.

Recording of intermediate states by interviews

Interviews in certain intervals in the course of the instructional process are a further important method mostly applied in addition to the continuous data collection (Scott, 1987; Brown, 1987; Lewis, 1991; Hammer, 1991; Lichtfeldt, 1992).

Cognitive analysis of the final state

In physics education there are numerous papers describing the success of learning quantitatively by differences of scores between pre-instructional and post-instructional tests and comparing them with other instruction methods. In some cases, a sort of cognitive analysis of the final state achieved is attempted. Such an analysis of empirical results appears to be a valuable contribution to the analysis of learning processes. As one example for such investigations I only refer to the study of Galili, Bendall & Goldberg (1993).

4. Results

4.1 Learning as development of new cognitive structures

Description of cognitive structures relevant for didactics

A significant partial result of all those studies is a cognitive description of knowledge structures relevant for didactics. As far as content related descriptions are concerned, these can almost always be categorised somewhere between pre-instructional everyday conceptions and scientific conceptions as "intermediate conceptions". Physics learning thus appears as a process in which instruction incites the self development of the cognitive system and leads to intermediate states. These intermediate states have to be regarded as developmental steps on the pathway to a scientific view. They are perhaps determined both by the state of the cognitive system before instruction with its potential of development and by the specific concept of instruction.

Conceptual change

One of the first learning process studies in physics known to me (Schmidt, 1989; Schwedes & Schmidt, 1992) shows, in accordance with the then prevailing theory of conceptual change, a change from an initial conception "consumption" (Fig. 5) to a final conception "Ohm" (Fig. 6). Of specific interest in this study is the description of a cognitive state as "conception" by means of a "nucleus" and specific propsotional sentences referring to different single situations. The nucleus is regarded as the behavior organising structuring element, producing further specific views in interaction with specific situations. From today's view one would perhaps characterise the final state achieved by the fact that it represents the initial conception as well as the final conception (and possibly even others) with different powers and different status.

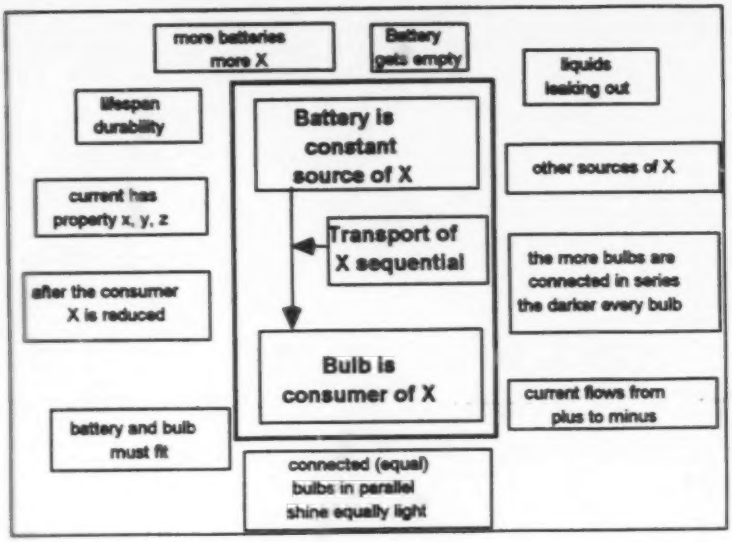


Fig. 5: Initial conception with nucleus "consumption

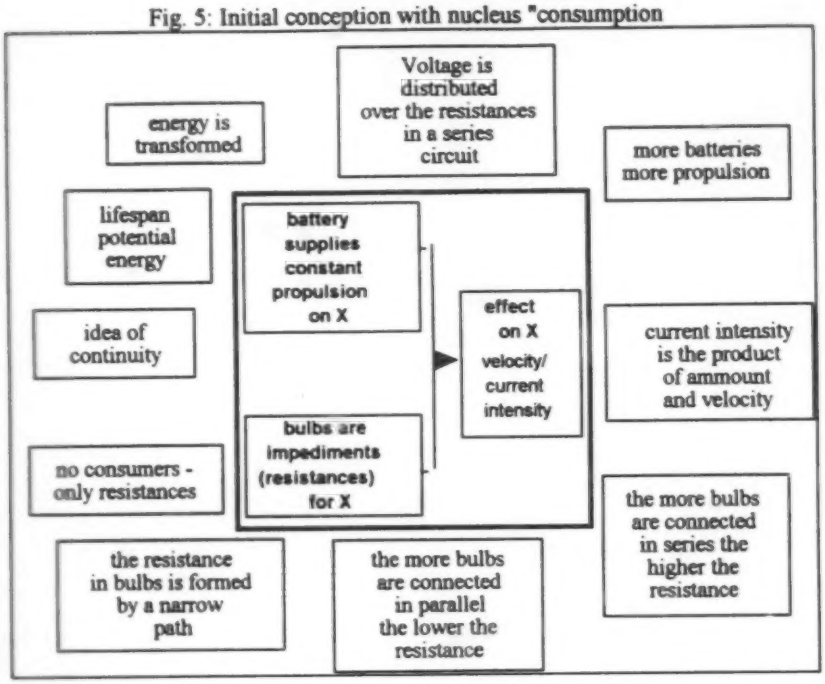
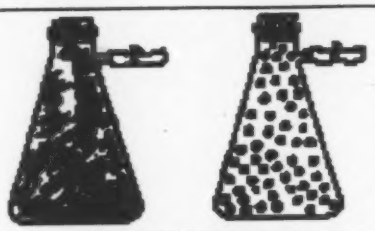


Fig. 6: Final conception with nucleus "Ohm"

Layers in the final cognitive state

The aspect of the simultaneous existence of different cognitive structures in the final state achieved after teaching has been described for the first time and very impressively in the work of Scott (1987, 1992). He investigates in his "pathways in learning science" one student Sharon during instruction aiming at a particle conception of solids, liquids, and gases.

Fig. 7: A closed flask containing air	Fig. 8: A closed flask after some air has been taken out
	
Sharon's drawing Before After teaching	Sharon's drawing Before After teaching

(Scott 1987, 1992)

At the end of the unit she appears to dispose of both conceptions (gas as a continuous substance and gas as an accumulation of small particles) and is able to distinguish between them. In everyday life (e.g. when talking to her mother) she would apply the old, continuous conception, however, discussing with her teacher she would make use of the new conception in various explanations (Scott, 1992, p. 222). In a similar way, Niedderer & Goldberg (1992, p. 15-18), during their analysis of an action sequence at the end of an instruction unit, find that students recur to different "layers" of their cognitive system in the course of their 20 minutes discussion on the explanation of a new experiment. These layers comprise, among others, the intitial conception, an intermediate conception and parts of the scientific conception aimed at.

Achievement of cognitive states not intended

A further important general result of learning studies in physics is the evidence that students achieve cognitive states not intended by the teacher which, normally, are between the initial conceptions and scientific theory. One example for such process is given in the study of Galili, Bendall & Goldberg (1993) in the field of optics.

In addition of the description of this conception by iconical representations (see below), the authors use also verbal propositional descriptions of the "core concepts" and the "main ideas". They call the particularly interesting intermediate state achieved after instruction as a result of physics learning the "relevant ray conception". It is characterised by the fact that only a selection of relevant rays are used for image construction, consequently leading in some situations to characteristic mistakes, while the scientific image construction takes in consideration all light rays emanating from an object. The authors call the knowledge achieved at the end of the instruction as "hybrid knowledge" characterising an "intermediate state".

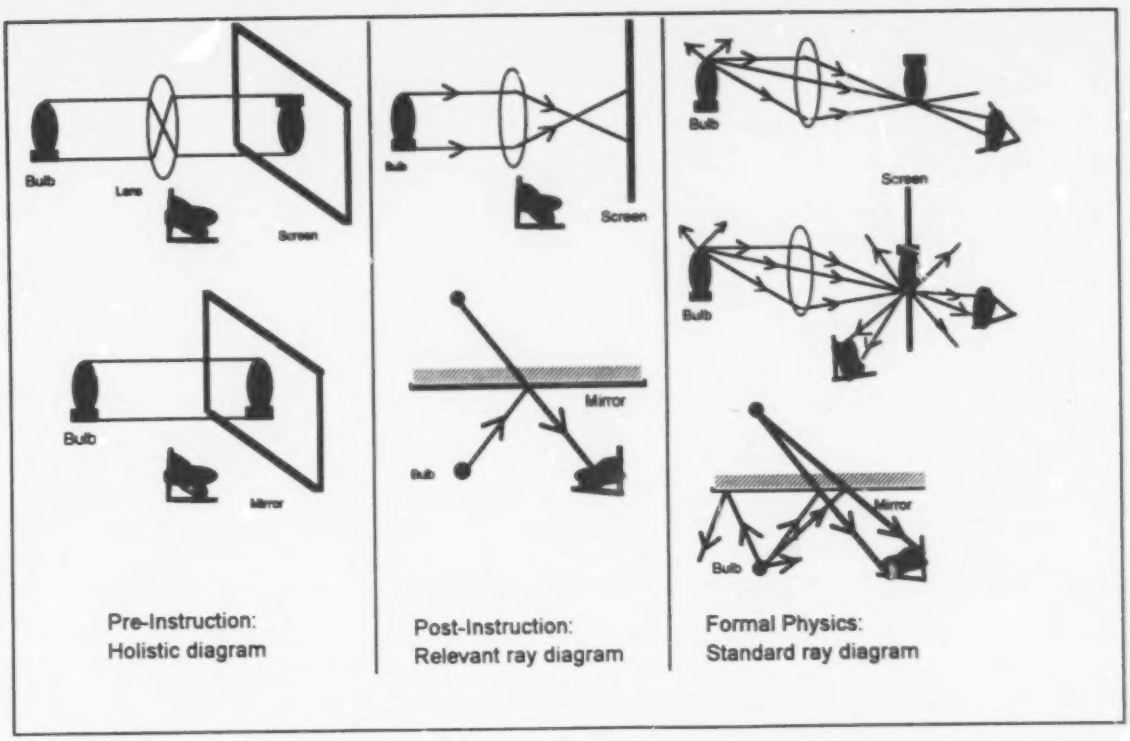


Fig. 9: Optical image construction by rays. Comparison of conceptions before and after instruction with the physical concept. According to Galili, Bendall & Goldberg (1993, p. 296)

Such intermediate states achieved by students of different age groups during the learning process are described as well by Niedderer & Goldberg (1995) for electric circuits, by Lewis (1991) for thermodynamics, and by Dykstra (Dykstra, 1992; Dykstra et al., 1992) relating to the mechanical concept of force. In connection with the idea of self development of the cognitive system I formulate a general hypothesis: There are significant content related intermediate conceptions frequently developed by students of different age groups in physics learning independent of the particular teaching concept. They could be denominated as "attractors of the cognitive development".

Describing learning pathways

Some studies come to describe learning pathways by means of intermediate states achieved. Already Scott (1987, 1992) uses the term "conceptual pathway" to describe such a learning pathway. More explicitly such learning pathways are described by Lewis (1991), Lichtfeldt (1992), Niedderer & Goldberg (1995), and Petri (1996).

Lewis (1991) starts with listing five "target scientific conceptions" in a table (table 2, p. 46-48): thermal equilibrium, conduction, insulation, heat energy, and temperature. She compares these scientific conceptions to several "intermediate conceptions" and "misleading intuitive conceptions". The learning process is subdivided in relation to each of these five target conceptions as the pathway leading from the "intuitive conception" to the "target conception" via five "levels of explanation". This process is shown for individual students (see the bottom of fig. 17). The intermediate steps are indicated as "encoding new facts without explanations", "mixed predictions, idiosyncratic explanations", "mixed predictions, explanations", and "good predictions, mixed explanations". This description of learning process thus is a mixture of qualitative description of the changes from "intuitive

conceptions" via "intermediated conceptions" to "target conceptions" with a quantitative description via the level of explanation.

Lichtfeldt (1992) uses so-called networks of ideas to show cognitive states. In particular, he describes in detail the learning pathway of a student in the domain of quantum physics as a dynamic development (change) of networks of ideas including eleven stations each represented by such a network of ideas. In the networks of ideas the crucial terms of the initial conceptions as well as of the target conceptions are included, and the marked relations are gained by analysing transcripts from instruction or from interviews, respectively.

The learning pathway is shown as a step by step development of the networks over many stations and on the whole shows a process of increasing links by new relations between the conceptions disclosing also the weight of a particle oriented description of electrons to a description of the electrons as quantum objects, and thus a qualitative change of the conceptions. (Individual case study of one student, Lichtfeldt 1992, p. 295-353).

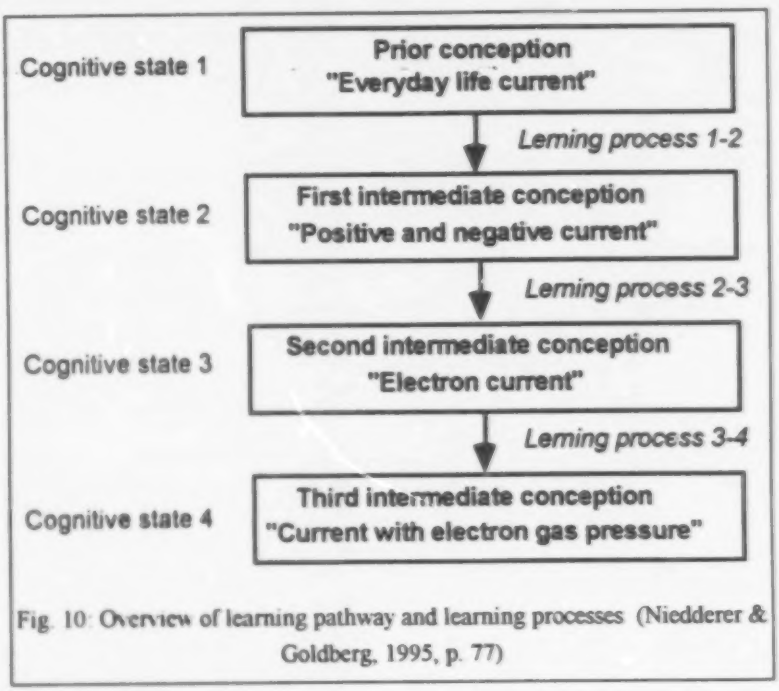
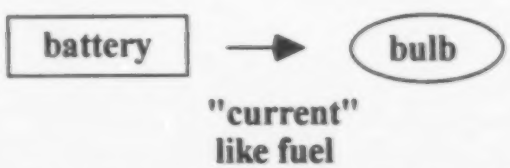


Fig. 10: Overview of learning pathway and learning processes (Niedderer & Goldberg, 1995, p. 77)

Niedderer & Goldberg (1995) show the learning pathway in the course of two double lessons by a sequence of four cognitive states characterised by the relevant conceptions. Each of these conceptions is described by core statements and complementary statements as well as by iconic representations. As an example the description of the initial conception "everyday current conception":

The prior conception "**EDL-current**":
Current is seen as a substance, containing energy like fuel.
Special facets:
- "electricity": substance like fuel, energy
- current consumtion
- "movement" (flow 'to', flow 'through'), and
- from battery through wires to the bulb



This conception is used extensively throughout the whole process giving its meaning to the words "current" and "pressure". That means that these concepts get a bias which relates them directly to effects like brightness of bulbs, number of bulbs and batteries, no matter whether there is a parallel or series circuit.

Fig. 11: Initial "everyday current conception" (Niedderer & Goldberg, 1995, p. 77)

Supplementary to the description of learning pathways by cognitive states they attempt to reconstruct also the learning processes as processes of modification of the cognitive system as a result of the course of instruction. In this case the analysis of trancripts supplies ideas what cognitive tools - for example everyday conceptions, schema,

or elements of colloquial speech - are used to construct those intermediate conceptions. Their analysis of "knowledge construction" pursues two goals:

- to formulate hypotheses on the effects of single teaching elements on the construction of intermediate conceptions, and
- to formulate hypotheses on the cognitive tools used by the students in the learning process.

Examples for such hypothetical cognitive tools used for developing the cognitive intermediate state "electron current" are listed below (see Fig. 12).

Hypothetical cognitive tools used for knowledge construction
Students make sense of the teaching input "electron" by using certain cognitive tools like "electron as a particle" or other cognitive tools from everyday life language like to travel, to stay, to push etc., thus constructing their new intermediate conception "microscopic view of electron current".

Cognitive tools specifically related to electric circuits
- electron as a particle;
- charge (positive and negative); electrons are negatively charged; this might lead to repelling (forces) between them and to attracting (forces) from the positive end of the battery

Cognitive tools of everyday language
(contributing to knowledge construction of this intermediate conception in a similar way as schema)
- electrons can move, go up there, not stay there; electrons can travel, they can stop, go back (to the battery); the movement has a unique direction; they can keep going; they flow (in circular motion)
- electrons can push other electrons or atoms; they can be pushed; thus electrons make movement of atoms in bulb (which causes light production); and electrons themselves can be moved that way.
- number of electrons; the number of electrons can be seen the same moving in and out of bulb or battery (conservation)
- electrons need some room to move; nowhere to go means that no movement is possible

Fig. 12: Hypothetical cognitive tools for developing the conception "electron current"
(Niedderer & Goldberg 1995, p. 81)

The cognitive intermediate state "electron current" is then described as follows:

Intermediate conception "electron current" (microscopic view of current)

Center (nucleus) of this conception: Protons stay, electrons move, in a circular motion, going from battery to bulb in one wire and back in the other (different directions). Motion of electrons makes movement in bulb and produces heat and light. The motion is driven by repelling and attracting forces from the battery. Conservation of number of electrons seems intelligible, but is not seen consistently as a rule, electrons still have the - additional - meaning of "fuel". Amount of current is not seen consistently in relation to speed of electrons.

Fig. 13: Second intermediate conception "electron current"
(Niedderer & Goldberg 1995, p. 81)

4.2 Learning as modification of the characteristics of already existing or newly developed cognitive structures

Learning as a modification of "status"

Hewson & Hennessey (1992) describe the learning process of a girl student on the force conception as a modicification of the "status of students' conceptions". The study is dealing with Newton's third law, especially

with the example of a book on a table experiencing two forces, that of weight and a counterforce exerted from the table. The authors describe the conception and its status before, during, and after instruction, and six weeks later. The conception changes rather quickly from an everyday conception to a scientific conception the status of which is getting higher in the sense of "intelligibility", "plausibility", and "fruitfulness" in the course of teaching.

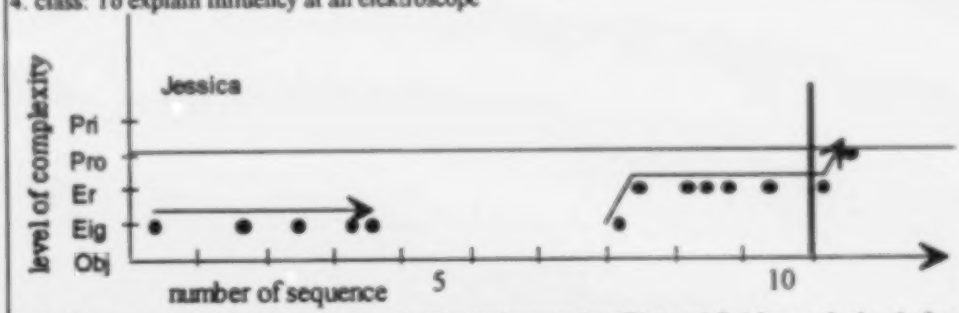
Learning as development of "complexity"

In the last ten years the group von Aufschnaiter in Bremen worked on several research projects on the subject of learning as development of complexity of construction of meaning of individual students in physics learning (Fischer, 1989; Fischer & von Aufschnaiter, 1992; Welzel, 1994). In order to characterise the levels of complexity a taxonomy originally developed by Powers (1973) is used. Welzel (1994) uses the following levels of complexity: the level of objects, the level of characteristics, the level of events, the level of program, and the level of principles. These levels of complexity can partly also be regarded as an increasing level of abstraction. In this sense four of the five levels (level of objects, level of characteristics, level of program, and level of principles) are common also in other relevant physics papers. The author determines learning as a process in the course of which the student learns to arrive sooner and more successfully to higher levels of complexity in similar future problem solving situations:

"The cognitive system has learned something if prior constructions of meaning and their development have effected that in new (similar) situations sooner successful actions are organised and thus sooner discrepancies between observation and expectance in the new situation are diminished. ... Learning thus means that those developments of meaning proving to be helpful are strengthened in the procedures generating them (and those not proving to be helpful are weakened), so that the strengthened procedures generate "their" processes with greater probability and the weakened with reduced probability at the next occasion." (Welzel, 1994, p.32)

The two subsequent figures show the development of complexity of constructions of meaning of an individual student Jessica in instruction sequences of 20 minutes each in similar situations in the 4th and 6th double lesson of the unit:

4. class: To explain influency at an elektroscope



"The development of meaning starts at the level of properties (Eig) and finishes at the level of programmes (Pro) ..."

6. class: A similar experiment with an electroscope

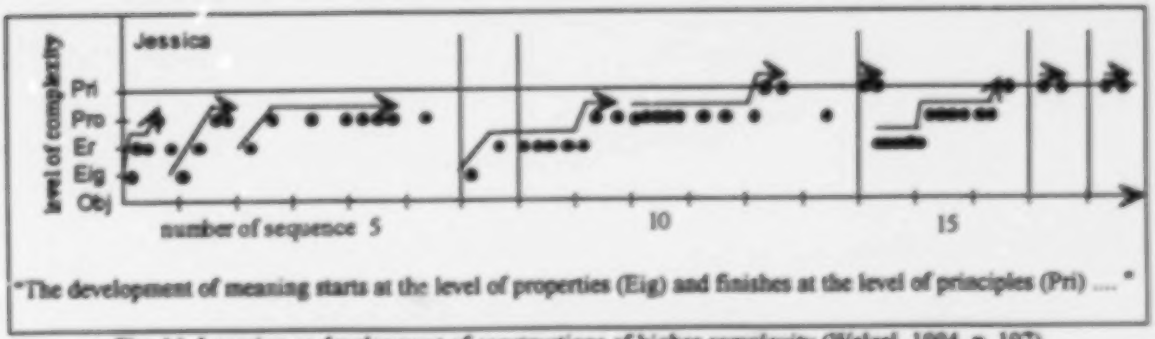


Fig. 14: Learning as development of constructions of higher complexity (Welzel, 1994, p. 197)

From the comparison of both diagrams the earlier achievement of higher levels of complexity in the 6th double lesson is to be interpreted as learning.

Learning as an increase of the "power" respectively "probability of use" of a cognitive element

Learning has also in its everyday language meaning something to do with the competence in the use of knowledge. In this sense learning can be understood as an increase of the "power" or "probability of use" of a cognitive element. Niedderer (1972) supplies an example by investigating the increase of number of correct predictions when connecting various sources and consumers in the electric circuit (see Fig. 15).

In Brown (1994) there is a similar description to be regarded as an increase of probability of use of the correct answer ("counterforce of the table exerted on the book lying on the table" after the "treatment" of seven similar examples (see Fig. 16).

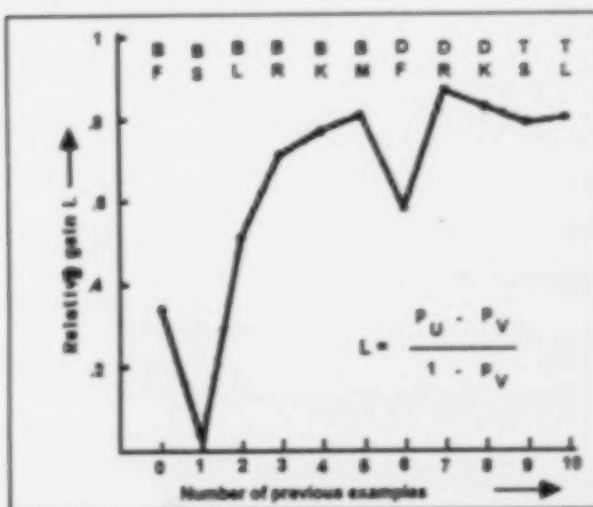


Fig 15: Learning as increase of the probability of correct predictions (Niedderer 1972, p. 58)

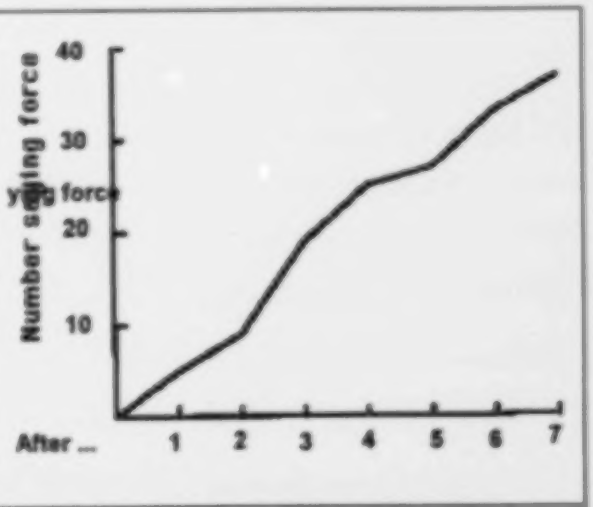


Fig. 16: Learning as increase of the percentage of correct explanations (number of students saying the table exerts a force versus point in the series of explanation) (Brown 1994, S.208)

Learning as an increase in the level of explanation

A description taking up rather the qualitative characerterisation of the modification of cognitive elements is found in Lewis (1991). She describes the modification of levels of explanations during instruction with respect to four different contextual dimensions. This increase of the level of explanation is gathered for individual students from the analysis of a total of seven interviews/tests and graphically shown as follows:

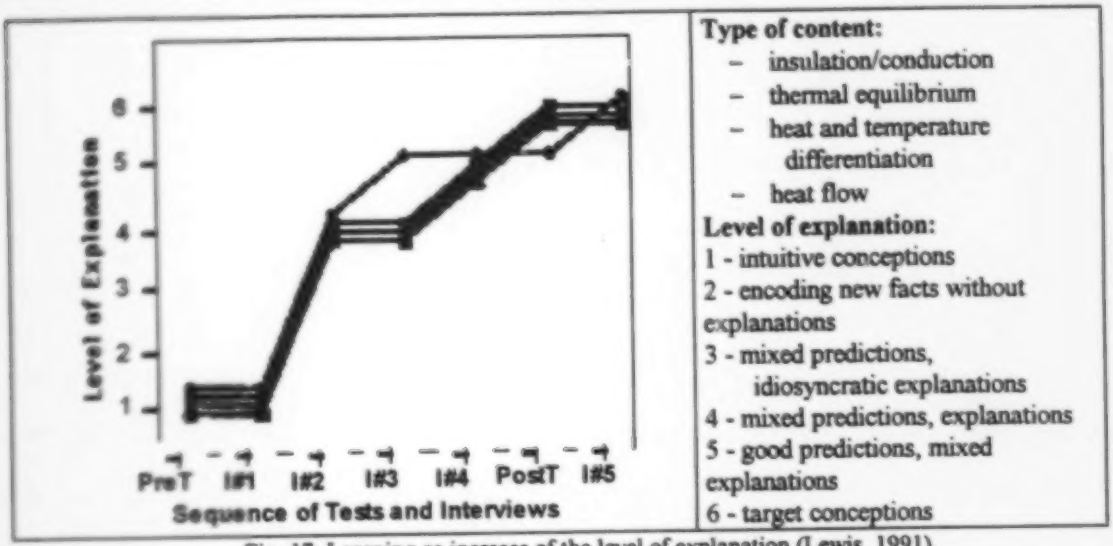


Fig. 17: Learning as increase of the level of explanation (Lewis, 1991)

4.3 Instructional conditions of learning

Intermediate conceptions as "stepping stones"

Brown & Clement (1992) report on classroom experiments in mechanics leading to an improvement of successful learning by explicitly attempting to use students' intermediate concepts. The subject dealt with was, among others, the physical conception of inertia. As intermediate concepts the teacher used the following:

- "hold back tendency"
- "keeps going tendency"

The authors consider these intermediate concepts as stepping stones of learning. They are convinced by the results that explicitly aiming at these intermediate conceptions has improved the learning results and helps both students and teachers to clarify important points. Tiberghien (1997) [3] takes the same view.

Statement of resonances between teaching input and self development of the cognitive structure

In their study Niedderer & Goldberg (1995) start from a constructivist learning model and see the connection between the teaching offer (teacher information and behavior, texts, experiments, actions) and actual learning as

---

[3] Paper to be published soon.

"resonance" ("compatibility" or "conceptual fit", Glasersfeld, 1992, p. 33) in the following sense: Depending on the individual cognitive structure of the student different parts of the learning offer have more or less significant effects. In case of positive effects of certain teaching inputs they speak of resonance between teaching information and cognitive system of the student. This idea has been formulated in a particularly impressive way by Ernst von Glasersfeld in a discussion during the Bremen workshop on learning process studies. He talked of a pizzicato violin sound (teaching input) which may bring back an echo in a room (cognitive construction) as a resonance as far as sound and structure of the room "fit together".

Such resonances Niedderer & Goldberg (1995) find when introducing the "language of electrons" in their above identified study which was done by the teacher only "incidentally". The students willingly responded to most of the teacher's information and went on constructing their own ideas thus being able to do substantial reasoning about current themselves. This is explained by the fact that the offered electron modell of current permits the students to make use of numerous already existing cognitive tools (see the list shown above). Another portion of the positive resonance is put down to the high estimation of these students for atomic miscroscopic models as "true physics".

Adaptation of the level of complexity of the teacher to that of the students

Welzel and von Aufschnaiter (in personal notice) have following hypotheses on possible consequences for improvement of teaching out of their research results:

- teachers must be aware of and able to analyse the level of complexity used by their students. They have to adapt their own information to the students to their level of complexity.
- students have to get enough time to develop constructions on their present level of complexity.
- students' social construction processes in free working teams are of particular significance for the learning process.

With respect to the influence of interactions on learning environments (Welzel, 1994) it has to be stated on the basis of these results that even by interactions information cannot be transferred but that during interaction processes in the student's cognitive system are started. The course of these processes depends essentially on the cognitive system itself and its ability to link experiences in relation to the learning environment. Developments of meaning therefore are (more or less surprisingly) individual.

To promote the process of development of meaning therefore the student's experience must be able to be included in the interaction. As no one can know somebody else's experiences in their possibilities it is important to observe the actions of the learner in order to see on what level he solves problems at this moment and to give him chances for building up relations starting from this level.

5. Conclusions

- Learning is to be seen as self development of the cognitive system: Learning perhaps is more influenced by cognitive tools in the mind of the students than by specific types of teaching. Thus, learning processes in physics education with the aim of coming to concepts of physics frequently come to intermediate conceptions, determined by the application of those tools. These intermediate conceptions lie often between prior conceptions and the scientific conceptions. We can observe intermediate conceptions in students' thinking which were never intented by the teacher, sometimes not even recognised by him.

- In many cases many different types of teaching come to the same intermediate conceptions. Those intermediate conceptions which are characteristic for the dynamics of the development of the cognitive system itself, we call them attractors of the cognitive development of students in the specific content area.

- To analyze the role of basic cognitive tools in students' learning processes and their influence on resonance or non-resonance of learning with teaching is a research goal with high priority. Possible types of cognitive tools are: Basic conceptions like "particle", "fluid", "food" or "fuel"; basic schema or p-prims like Ohm's p-prim or the consumtion schema; simple basic parts of natural language related to those other basic tools.

- There might be a new view on learning states after teaching: It might be a better picture of the final state of learning after teaching if we think of different layers with different "strength" and "status", which are activated by the student in different ways: some are easy and come first (high strength), others are more relevant (high status), but come later. So, giving more time in final examinations might be an important way to come to better results about knowledge of students after teaching.

6. References

Aufschnaiter, S. v.(1991). Lernen ist Selbstentwicklung eines kognitiven Systems. In Wiesner, H. (Hrsg.), Aufsätze zur Didaktik der Physik II. Bad Salzdetfurth: Franzbecker, 1-11.

Brace, G.R. (1988). The design of an instructional model to transform students' alternative frameworks of dynamics. M.A. thesis. University of British Columbia .

Brown, D.E. (1987). Using analogies and examples to help students overcome misconceptions in physics: a comparison of two teaching strategies. Dissertation. Amherst, MA: University of Massachusetts, University Microfilms # 8805897 .

Brown, D. & Clement, J. (1992). Classroom teaching experiments in mechanics. In R. Duit, F. Goldberg & H. Niedderer (Eds.), Research in physics learning - Theoretical issues and empirical studies. Proceedings of an International Workshop in Bremen. Kiel: IPN, 380-397.

Brown, D.E. (1994). Facilitating conceptual change using analogies and explanatory models. International Journal of Science Education 16, 2, 201-214 .

Carmichael, P., Driver, R., Holding, B., Phillips, I., Twigger, D. & Watts, M. (1990). Research on students' conceptions in science: A bibliography. CLIS Group, University of Leeds.

Duit, R., Goldberg, F. & Niedderer, H. (Eds.) (1992) Research in physics learning - Theoretical issues and empirical studies. Proceedings of an International Workshop in Bremen, IPN: Kiel.

Duit, R., & Treagust, D. (1997). Learning in science - From behaviourism towards social constructivism and beyond. In B. Fraser & K. Tobin, Eds., International handbook of science education. Dodrecht, The Netherlands: Kluwer (in press).

Dykstra, D. (1992). Studying conceptual change: Constructing new understandings. In: Duit, R., Goldberg, F. & Niedderer, H. (Eds.): Research in Physics Learning: Theoretical Issues and Empirical Studies. Proceedings of an International Workshop at the University of Bremen. Kiel: IPN, 40-58 .

Dykstra, D.I., Boyle, C.F. & Monarch, I.A. (1992a). Studying conceptual change in learning physics. Science Education 76, 6, 615-652 .

Fischer, H. (1989). Lernprozesse im Physikunterricht - Falluntersuchungen im Unterricht zur Elektrostatik aus konstruktivistischer Sicht. Dissertation Universität Bremen .

Fischer, H.E. & Aufschnaiter, S.v. (1992). The increase of complexity as an order generating principle of learning processes. Case studies during physics instruction. In: Duit, R., Goldberg, F. & Niedderer, H. (Eds.): Research in Physics Learning: Theoretical Issues and Empirical Studies. Proceedings of an International Workshop at the University of Bremen. Kiel: IPN .

Fischer, H. (1994). Physiklernen: Eine Herausforderung fuer die Unterrichtsforschung (Physics learning: A demanding task for instructional research). Frankfurt a.M.: Lang, Habilitation Universität Bremen.

Fischler, H. & Lichtfeldt, M. (1992). Learning quantum mechanics. In: Duit, R., Goldberg, F. & Niedderer, H. (Eds.): Research in Physics Learning: Theoretical Issues and Empirical Studies. Proceedings of an International Workshop at the University of Bremen. Kiel: IPN .

Galili, I., Bendall, S. & Goldberg, F. (1993). The Effects of Prior Knowledge and Instruction on Understanding Image Formation. Journal of Research in Science Teaching 30(3), pp. 271-301.

v. Glasersfeld, E. (1992). A constructivist's view of learning and teaching. In R. Duit, F. Goldberg & H. Niedderer (Eds.), Research in physics learning - Theoretical issues and empirical studies. Proceedings of an International Workshop in Bremen. Kiel: IPN, 29-39.

Hammer (1991). Defeying Common Sense: Epistemological Beliefs in an Introductory Physics Course. Unpublished doctoral dissertation, University of California, Berkeley.

Hennessey, M.G. (1991). Analysis of conceptual change and status change in sixth gradeers' concepts of force and motion. Unpublished doctoral dissertation, University of Wisconsin-Madison.

Hericks, U. (1993). Über das Verstehen von Physik. . Waxmann, Münster, New York. (Dissertation Universität Münster) .

Hewson, P. & Hennessey, M.G. (1992). Making status explicit: A case study of conceptual change. In: Duit, R., Goldberg, F. & Niedderer, H. (Eds.): Research in Physics Learning: Theoretical Issues and Empirical Studies. Proceedings of an International Workshop at the University of Bremen. Kiel: IPN .

Johansson, B., Marton, F. & Svensson, L. (1985). An Approach to Describing Learning as Change between Qualitatively Different Conceptions. In: West, L.H.T. & Pines, A.L. (Eds.): Cognitive Structure and Conceptual Change. Orlando: Academic Press, 233-257

Jung, W. (1992). Probing acceptance: A technique for investigating learning difficulties. In: Duit, R., Goldberg, F. & Niedderer, H. (Eds.): Research in Physics Learning: Theoretical Issues and Empirical Studies. Proceedings of an International Workshop at the University of Bremen. Kiel: IPN .

Katu, N. (1992). Development of Conceptions in Basic Electricity: An Exploratory Study Using Teaching Experiment Methodology. Unpublished Ph.D. dissertation, The Pennsylvania State University: University Park, PA, USA. .

Katu, Nggandi; Lunetta, Vincent N. & van den Berg, Euwe (1993). Teaching Experiment Methodology in the Study of Electricity Concepts. In: The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics .

Komorek, M. & Duit, R. (1995). A learning process study on elementary features of chaos theory. Paper presented at the conference "Science Education Research in Europe", Leeds.

Lewis, E. L. (1991). The Process of Scientific Knowledge Acquisition Among Middle School Students Learning Thermodynamics. Doctoral Dissertation, University of California at Berkeley

Lichtfeldt, M. (1992). Schülervorstellungen in der Quantenphysik und ihre möglichen Veränderungen durch Unterricht. Essen: Westarp (Dissertation Freie Universität Berlin) .

Niedderer, H. (1972). Sachstruktur und Schülerfähigkeiten beim einfachen elektrischen Stromkreis (Content structure and student abilities in simple electric circuits). Doctoral dissertation, University of Kiel

Niedderer, H. & Schecker, H.(1992). Towards an explicit description of cognitive systems for research in physics learning. In R. Duit, F. Goldberg & H. Niedderer (Eds.), Research in physics learning - Theoretical issues and empirical studies. Proceedings of an International Workshop in Bremen. Kiel: IPN, 74-98

Niedderer, H. & Goldberg, F. (1995). Lernprozesse beim elektrischen Stromkreis. Zeitschrift für Didaktik der Naturwissenschaften (ZfDN) 1 (1995), 73-86 .

Petri, J. (1996). Der Lernpfad eines Schülers in der Atomphysik - eine Fallstudie in der Sekundarstufe II. Dissertation. Universität Bremen

Pfundt, H. & Duit, R. (1994). Bibliographie Alltagsvorstellungen und naturwissenschaftlicher Unterricht, 4. Auflage. Kiel: IPN.

Powers, W. T. (1973). Behaviour: The control of perceptions. Aldine Publishing Company, Chicago.

Roschelle, J. (1991). Students' Construction of Qualitative Physics Knowledge: Learning About Velocity and Acceleration in a Computer Microworld. Doctoral Dissertation. Berkeley, CA: University of California .

Schmidt, D. (1989). Zum Konzeptwechsel. Frankfurt a.M.: Lang (Dissertation Universität Bremen) .

Schwedes, H. & Schmidt, D. (1992). Conceptual change: A case study and theoretical comments. In: Duit, R., Goldberg, F. & Niedderer, H. (Eds.): Research in Physics Learning: Theoretical Issues and Empirical Studies. Proceedings of an International Workshop at the University of Bremen. Kiel: IPN .

Scott, P. H. (1987). The process of conceptual change in science: A case study of the development of a secondary pupil's ideas relating to matter. Unpublished thesis submitted in partial fulfilment of MEd., University of Leeds

Scott, P. (1992). Conceptual pathways in learning science: A case study of the development of one student's ideas relating to the structure of matter. In: Duit, R., Goldberg, F. & Niedderer, H. (Eds.): Research in Physics Learning: Theoretical Issues and Empirical Studies. Proceedings of an International Workshop at the University of Bremen. Kiel: IPN .

Seibel, C. (1995). Analyse von Lernprozessen im handlungsorientierten Physikunterricht - Fallstudie einer elfjährigen Schülerin zum Thema Kurzschluß. Dissertation. Universität Bremen

Tytler, R. W. (1994). Children's Explanations in Science: A Study of Conceptual Change. Unpublished doctoral dissertation, Monash University Melbourne.

Welzel, M. (1994). Interaktionen und Physiklernen. Frankfurt a.M.: Lang, Dissertation Universität Bremen.

Wodzinski (1995). Untersuchungen von Lernprozessen beim Lernen Newtonscher Dynamik im Anfangsunterricht. Dissertation Universität Frankfurt.